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# A note on low scale unification and gamma-gamma scattering

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## Abstract

In this note we study an interesting effect of low energy gravity on photon-photon scattering at high energies.

In a recent paper Gounaris, Porfyriadis and Renard [1] have highlighted the possibility of exploring new physics through the scattering process  $\gamma\gamma \rightarrow \gamma\gamma$  at c.m. energies in the TeV range. The  $\gamma\gamma$  mode is a possible mode of operation in a  $e^+e^-$  linear collider and this makes the study of this particular scattering at TeV-scale useful in a very practical way and not just of purely theoretical interest. Recently a lot of interest has also been generated in a TeV-scale unification wherein one envisages a Kaluza-Klein (KK) scenario in  $(4+n)$ -dimensions [2, 3]. Ordinary matter and gauge fields are localized in a  $(3+1)$ -dimensional brane configuration whereas gravity propagates in  $(4+n)$ -dimension, with the  $n$ -extra dimension compactified. For  $n=2$ , the compactification scale turns out to be in the mm range with a weak Planck scale in the TeV range (which acts as a cut-off for all effective theories) and these numbers make this particular choice of  $n$  to be particularly interesting from the point of view of experiments in the collider.

In the scenario just outlined excitations of the gravitons in the compactified dimensions would appear in the  $(3+1)$ -dimensional world as towers of particles. At every level, there are one spin-2 state (massive), one spin-1 state and one spin-0 state. The spin-1 state decouple from ordinary matter [2, 3] and the spin-0 state couples through the dilaton mode. The spin-2 KK-modes with masses starting from the  $1/R$  scale and effectively cutoff at  $M_s$  (that is at some scale of the order of 1 or 2 TeV) couples to fermions and also to gauge particles and are the most visible signature of theories with compactification at low scale of the

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order of mms. The coupling of an individual KK-state is not of much interest since it is gravitationally suppressed, their interaction once summed over the towers of states however is significant. It gets an effective strength that can be phenomenologically relevant to processes in the TeV-scale. This note is to estimate such effects for  $\gamma\gamma$  scattering at the TeV scale. We show that the inclusion of the Spin-2 KK-excitations of gravitons in the TeV-range results in changes in the scattering amplitude that is definitely within the measurement range of experiments in the colliders.

Consider the scattering process:

$$\gamma(k_1, \lambda_1) + \gamma(k_2, \lambda_2) \rightarrow \gamma(k_3, \lambda_3) + \gamma(k_4, \lambda_4)$$

where the  $k$ 's and the  $\lambda$ 's refer respectively to momenta and helicities of the particles in the c.m. frame. The helicities take on values +1 and -1. The invariant scattering amplitude for this process is denoted by  $F_{h_1 h_2 h_3 h_4}(s, t, u)$  where the  $h$ 's take on values of signatures of the helicities and  $s, t$  are the usual Mandelstam variables. These amplitudes in the standard Model (SM) have been calculated by Jikia and Tkabladze [4]. At values of  $s$  and  $t$  such that  $s \gg -t \gg M_W^2$ , the amplitudes  $F_{++++}$  and  $F_{+--+}$  together with their parity equivalents dominate:

$$F_{++++}(s, t, u) = F_{+--+}(s, t, u) \quad (1)$$

$$F_{++++}(s, t, u) = (-16\alpha^2 i\pi)(s/t) \log(-t/M_W^2) \quad (2)$$

Let us now estimate the contributions coming from KK-excitations in all the three channels. The vertex connecting the KK-excitations with a pair of photons have been explicitly worked out by Han, Lykken and Zhang [3]. The resultant amplitudes have the symmetry:

$$F_{++++}(s, t, u) = F_{+--+}(u, t, s) \quad (3)$$

$$F_{----}(s, t, u) = F_{+--+}(u, t, s) \quad (4)$$

$$F_{-++-}(s, t, u) = F_{+--+}(s, u, t) \quad (5)$$

and

$$F_{+--+}(s, t, u) = (-i/4) * (\kappa^2) * (u^2) * [D(s) + D(t)] \quad (6)$$

$$F_{-++-}(s, t, u) = F_{+--+}(s, t, u) \quad (7)$$

where

$$D(s) = \sum \left( \frac{1}{s - M_{KK}^2} \right) \quad (8)$$

$M_{KK}$  denoting the mass of the KK-excitations and the summation is over the entire tower of excitations. In the last equation,  $M_{KK}$  is understood to include

the width  $-i\Gamma/2$  also.

The contribution of these KK-excitations are complex in general. However, in respect of SM contributions, Gounaris et. al. [1] have made the very important observation that the SM contribution is dominantly imaginary for values of  $s$  much greater than  $M_w^2$  for directions away from the forward. When the contributions coming from the KK-exchanges enter as corrections to the main SM contributions, clearly only the imaginary parts of the contributions become relevant. The important point to note is that in the expression for the amplitudes only the s-channel resonance contributes an imaginary part whereas the others are completely real. Thus, in the range of energies where the KK-contributions are expected to be in the nature of correction terms to the main SM contribution, only the s-channel resonance contributions need be taken into account. This means only  $F_{+-+}$  and  $F_{+--}$  together with their parity equivalents need be considered. The imaginary parts of the KK-resonance contributions come from the imaginary parts of the propagator denominators:  $(s - M_{KK}^2)$ . This is easily estimated following [3]. The imaginary parts of the amplitudes above are given by:

$$\sum \text{Im} \left( \frac{1}{s - M_{KK}^2} \right) = -\frac{\pi s^{n/2-1} R^n}{\Gamma(n/2)(4\pi)^{n/2}} \quad (9)$$

The nonvanishing contributions of the s-channel tower of KK-excitations to the imaginary parts of the amplitudes are thus given by:

$$\text{Im} F_{+-+} = \left( \frac{\kappa^2(1 + \cos \theta_s)^2}{2} \right) \left( \frac{\pi s^{n/2+1} R^n}{\Gamma(n/2)(4\pi)^{n/2}} \right) \quad (10)$$

where  $\theta_s$  is the c.m. scattering angle.  $\text{Im} F_{+--}$  is given by the above expression with  $\cos \theta_s$  replaced by its negative. Using now the relation (equation 64 of [3])

$$\kappa^2 R^n = M_s^{-(n+2)} (4\pi)^{n/2} \Gamma(n/2) \quad (11)$$

we get

$$\text{Im} F_{+-+} = \left( \frac{\pi(1 + \cos \theta_s)^2}{16} \right) (s^{1/2}/M_s)^4 \quad (12)$$

for  $n=2$ .

Multiple KK-excitation exchanges will give contributions proportional to higher powers of  $s^{1/2}/M_s$ . These cannot be computed in a straightforward manner and thus the single KK-exchange contribution is a reliable correction only in the domain where  $s^{1/2}/M_s$  is smaller than one. We exhibit in figure 1 and 2, the relative contributions to the imaginary parts of the amplitude  $F_{+-+}$  and  $F_{+--}$  in comparison to the SM predictions. All other SM amplitudes are negligible in this energy and angle values and as reasoned above, the magnitudes of the KK-contributions can be taken seriously when  $s^{1/2}/M_s$  is not too close to unity. It is clear that there will be a window, whose value will depend upon the value of  $M_s$ , wherein the KK-exchange contributions will act as a correction term to the SM-dominant term with a definite magnitude. Deviations of the

Figure 1

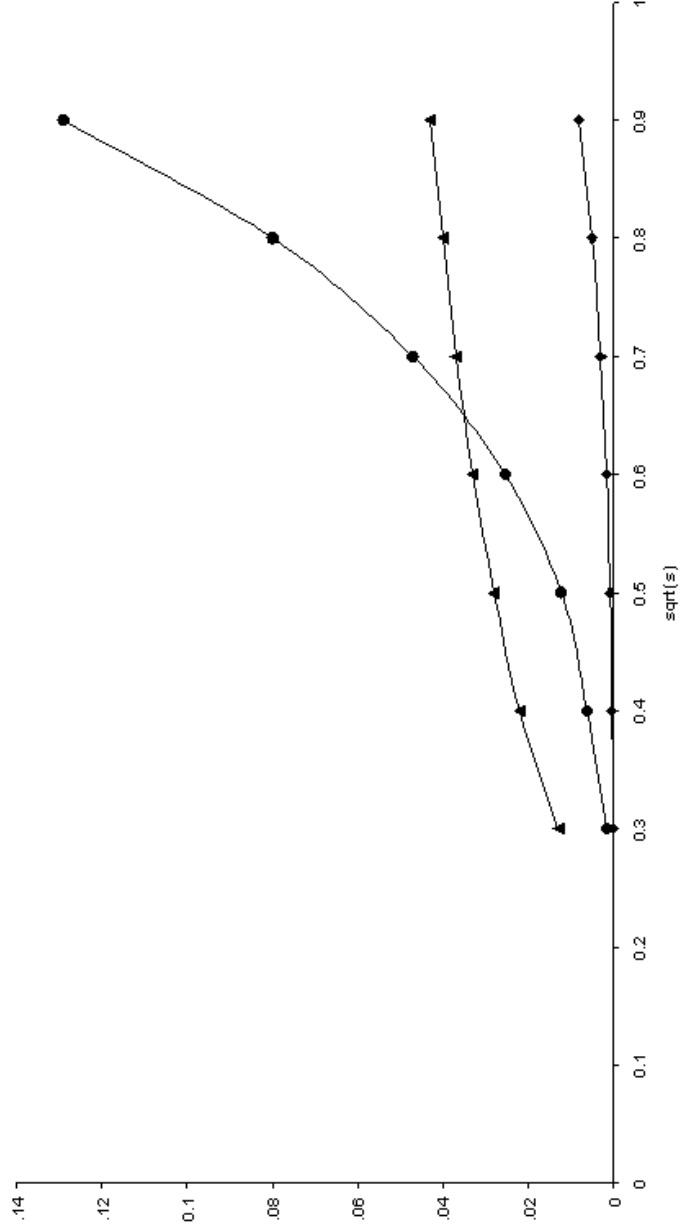


Figure 1: Magnitudes of the imaginary parts of the dominant SM amplitudes and the contributions coming from s-channel KK-excitations. The contributions for  $\theta_s = 90^\circ$  are represented by triangles for the SM contributions, by circles for  $F_{+--+}$  with  $M_s = 1TeV$ , and by diamonds for  $F_{+--+}$  with  $M_s = 2TeV$ . In this scenario, the amplitude  $F_{+--+}$  equals  $F_{+--+}$ .

Figure 2

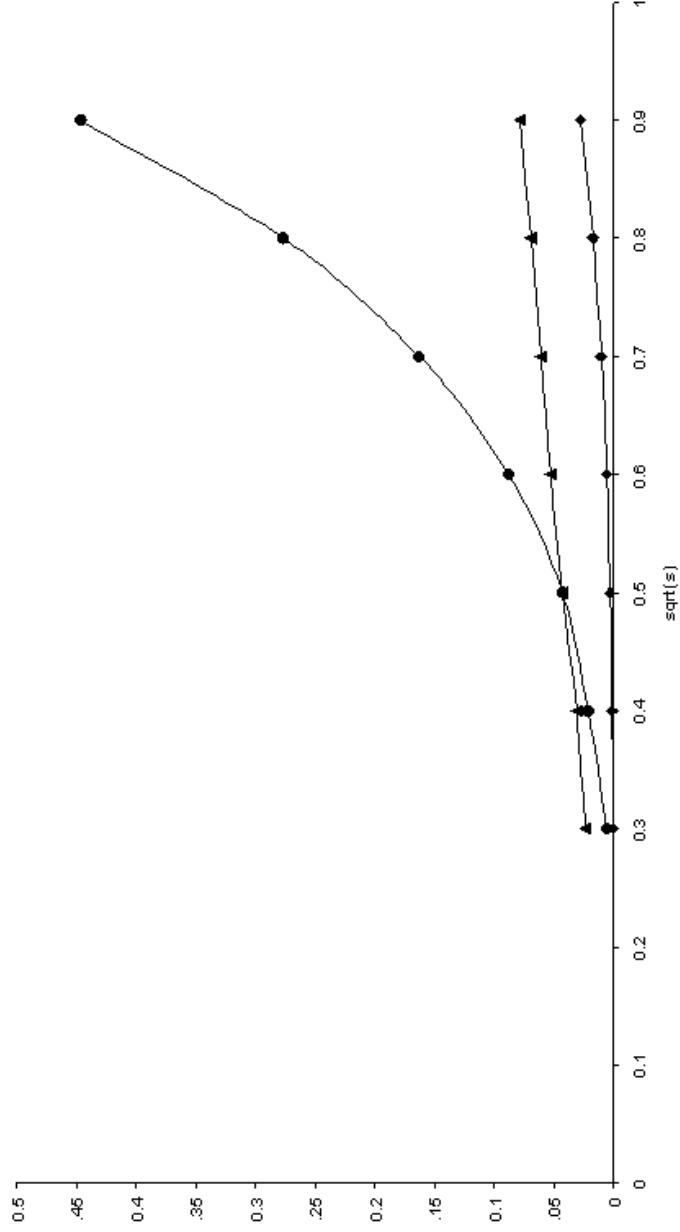


Figure 2: Magnitudes of the imaginary parts of the dominant SM amplitudes and the contributions coming from s-channel KK-excitations. The contributions for  $\theta_s = 30^\circ$  are represented by triangles for the SM contributions, by circles for  $F_{+--+}$  with  $M_s = 1TeV$ , and by diamonds for  $F_{+--+}$  with  $M_s = 2TeV$ . In this scenario, the amplitude  $F_{+--+}$  is negligible.

measured cross-sections from the SM can thus be fitted to the correction term with a single parameter  $M_s$  in the TeV. range. As the energies become higher so that multiple KK-exchange contributions become important as well, we are unable to calculate the KK-exchange contribution beyond saying that it will dominate the cross-section. We have calculated above the cross-sections away from the forward direction. Qualitatively similar conclusions of course can be drawn for the forward amplitude and hence for the total  $\gamma\text{-}\gamma$  cross-section also.

In conclusion, a low scale scenario leads to some definite pattern of deviation from the SM prediction for  $\gamma\gamma$  scattering. There exists a window at around a few hundred GeV. c.m. energy where the new physics gives rise a calculable correction to the SM values and thus provides a well defined signature. At still higher energies, the contributions coming from multiple KK-exchanges start dominating over the SM but do not lend themselves to estimation in any reliable manner.

After this work was completed the following related papers on photon-photon scattering appeared [5]. However, our note emphasizes the phenomenological importance of a window around the few 100GeV.

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